Cleveland, Ohio
NOISE-CON 2003
2003 June 23-25

Challenges in Acoustic Testing of ISS Payloads: Lessons Learned at the NASA Glenn Research Center Acoustical Testing Laboratory

James C. Akers
Analex Corporation
NASA John H. Glenn Research Center at Lewis Field
Cleveland, OH 44135
James.C.Akers@grc.nasa.gov

Paul J. Passe
Akima Corporation
NASA John H. Glenn Research Center at Lewis Field
Cleveland, OH 44135
Paul.Passe@grc.nasa.gov

Beth A. Cooper
NASA John H. Glenn Research Center at Lewis Field
Cleveland, OH 44135
Beth.A.Cooper@nasa.grc

ABSTRACT
The Acoustical Testing Laboratory (ATL) at the National Aeronautics and Space Administration (NASA) John H. Glenn Research Center (GRC) in Cleveland, Ohio, supports low-noise design of space experiment payloads. The ATL consists of a vibration isolated 100 Hz hemi-anechoic test chamber with 21 ft by 17 ft by 17 ft (h) interior working dimensions and removable floor wedges that allow the facility to be configured as either a hemi-anechoic or fully anechoic chamber. Currently, its primary customer is the Fluids Combustion Facility (FCF), a multi-rack microgravity research facility being developed at GRC for the USA Laboratory Module of the International Space Station (ISS). Over the past year and a half the ATL has conducted acoustic emission testing of components, subassemblies, and partially populated FCF engineering model racks. The ATL in collaboration with the Structural Dynamics Laboratory (SDL) has also supported combined vibration and acoustic emissions testing of the FCF engineering model racks. This paper will provide an overview of the current ATL facilities, capabilities, and acoustic testing performed, as well as plans for future improvements.

1. INTRODUCTION
The Acoustical Testing Laboratory (ATL) at the National Aeronautics and Space Administration (NASA) John H. Glenn Research Center (GRC) in Cleveland, Ohio, supports the development and qualification of low-noise design space experiment payloads. The ATL provides a comprehensive array of acoustical testing services, including sound pressure level, sound intensity level, and sound power level testing per ISO 3744[1] (NVLAP accredited).

Over the past year and a half the ATL has tested a variety of space payloads for the ISS with its primary customer being the Fluids Combustion Facility (FCF), a multi-rack microgravity research facility under development at GRC for the USA Laboratory Module of the International Space Station (ISS). ISS space experiment payloads have to meet ISS SSP 57000[2] acoustic noise emission requirements, which support hearing conservation, speech communication, safety goals, and to prevent noise-induced vibrations from deteriorating the on-orbit microgravity environment. These requirements include meeting an NC-like maximum sound pressure level criterion measured at a distance of 0.6 meters from a space experiment payload. For the FCF integrated racks this means that sound pressure level measured at a distance of 0.6 meters from the noisiest part of the rack must meet the criterion.

This paper will provide an overview of current ATL capabilities, highlight some of the testing that has been performed to date and the lessons learned from these tests, and briefly discuss plans for future improvements.

2. ATL OVERVIEW

The ATL facility consists of a reconfigurable anechoic/hemi-anechoic test chamber and an adjoining test support enclosure. The test chamber is physically separated from the adjoining test support enclosure and is supported on a spring-isolated concrete pad, providing vibration isolation down to 3 Hz. The interior working dimensions of the test chamber in the hemi-anechoic configuration are 21 ft by 17 ft by 17 ft (h). A 36 inch deep fiberglass anechoic wedge treatment with a high-open-area perforated metal facing provides a 100 Hz acoustic low frequency cutoff. Removable floor wedge carts can easily be installed in the test chamber, converting it to an anechoic chamber with a grating floor for the walking surface. The test chamber has double doors (9 feet wide by 10 feet high) and a removable ceiling plug (8 feet by 8 feet) that provides crane accessibility for working with large test articles. The adjoining test support enclosure is typically used as a control room, housing the ATL data acquisition system, as well as offices for the test engineer and facility technician. All control room furnishings are modular and easily movable. When test articles require services or support equipment yielding high noise emission levels, the control room furniture (including the ATL data acquisition system) is relocated out in the hallway of the host building while the test support enclosure provides sound-isolation of the support equipment from both the test article and test personnel. Both the test chamber and the test support enclosure have self-contained, separately silenced ventilation systems that provide heat removal and makeup air at 3000 cubic feet per minute and 1500 cubic feet per minute, respectively. The ATL test support enclosure and test chamber both have multiple utility penetration ports that allow cabling and hoses to be run from the test support enclosure into the test chamber, from inside the test support enclosure to outside the test support enclosure, and from inside the test chamber to outside the test chamber. Utility penetration ports not used during a test are filled with fiberglass and their ends sealed with metal end caps. Utility penetration ports used during a test are filled with cylindrical foam plugs and their ends sealed with plugs of duct seal after cabling and hosing have been passed through them.

The ATL PC-based data acquisition system uses National Instruments Sound Power System software (SPS) with Multi-Channel Enhancement software (MCE) written by Nelson Acoustical Engineering. The data acquisition system has four NI-4552 boards (4 input channels each) and one NI-4551 board (2 input channels and 2 output channels) housed in a Magma expansion chassis that is connected to a Dell Precision 420 workstation computer. The data acquisition system provides up to 18 channels of simultaneous data acquisition with real-time 1/1 octave band, 1/3rd octave band analysis and sequential real-time and narrowband FFT analysis. The SPS with MCE software generates a multi-worksheet Microsoft Excel workbook that thoroughly documents the test and provides for fast and efficient turn-around of data to the customer. Screenshots of the ATL data acquisition system during microphone calibration and data acquisition are shown in Figure 1. When calibrating microphones the software automatically computes the calibration offset and displays it for each microphone along with the calibration offset tolerance. The data acquisition window has two displays. The upper display plots the sound pressure level spectrum of a user selected data channel as well as giving the overall sound pressure level in dB and dBA for that data channel. The data channel selected in this upper display can be changed at any time during the data acquisition process, allowing detailed inspection of individual data channels. The lower display is a color contour plot of the sound pressure level spectrums of all the data channels color coded to magnitude. This provides the user a way to easily monitor all data channels and indicates data channels that may not be functioning properly. Finally, the software also has a noise intrusion alarm that signals when the noise level within the host building, measured with a reference microphone on top of the ATL test support enclosure, is producing a noise level inside the test chamber that exceeds a user defined limit.

The ATL test request policy and test planning procedure help facilitate communication between customers and the ATL staff to ensure a successful test. The ATL test request policy and the test request forms can be accessed from the ATL website: http://facilities.grc.nasa.gov/atl/atl_policy.html. This website also provides general information about ATL capabilities and services as well as information on industrial noise control, ISS noise criteria and materials, and hearing conservation. A potential customer makes a request for testing by submitting a Level 1 ATL Test Request form. The Level 1 form identifies the overall type of testing needed along with any items such as special test fixturing, handling procedures, or data acquisition capabilities requiring a long lead time to develop and/or fabricate. The Level 2 form provides further details of the test such as refinement in the number and type of transducers, their locations, handling and safety issues, and the test matrix. Typically a final test planning meeting is held at least a month prior to the scheduled test start date to finalize all details of the test. After the final test planning meeting, ATL generates a test plan, which is electronically transmitted to the customer typically two weeks prior to the scheduled test start date.

3. FCF COMPONENT AND SUBASSEMBLY TESTS

The ATL has tested FCF components, subassemblies, and partially populated engineering models of both the Combustion Integrated Rack (CIR) and the Fluids Integrated Rack (FIR). This range in size of test articles required a variety of test fixtures. For components and assemblies that weighed less than approximately 100 lbs the ATL test chamber was configured in its anechoic configuration. Typically a rectilinear six microphone array at a distance of two feet (0.6 meters = 23 5/8 inches) is used to measure the sound pressure level spectrum on all six sides of the component. These components and assemblies were supported with an FCF Customer supplied test fixture if available or a test fixture supplied by ATL.

The smallest FCF components tested were the Input Output Processor (IOP) hard drives, the IOP muffin fans, and the Gas Chromatograph (GC) pump. The challenge presented in testing the IOP hard drives was providing adequate support while not changing their mechanical vibration characteristics and allowing sound pressure level measurements on all six sides. A bridle system was used to support the IOP hard drives. While this bridle system did provide excellent access on all sides and did not interfere with the vibration of the hard drive, orientation of the hard drive proved somewhat cumbersome. The IOP hard drive suspended in the bridle with the microphone array in place is shown in Figure 2. The noise signature of the IOP hard drives were assessed during startup, idle, sequential read/write and random read/write operating conditions. The support computer used to power and control the IOP hard drive was located inside the adjoining ATL test support enclosure. The computer cabling running from the support computer to the IOP hard drive passed through one of utility penetration ports that pass through the West wall of the test support enclosure and the East wall of the test chamber. The cabling being passed through one of the utility penetration ports in the test support enclosure is shown in Figure 2.

The CIR combustion chamber has been the heaviest FCF subassembly tested. The noise generators on the combustion chamber are the two circulation pumps attached to its aft end. Sound pressure levels at a distance of two feet from the aft end of the combustion chamber were measured to characterize the noise signature of the circulation pumps when connected to the combustion chamber. The combustion chamber and its support stand were too heavy to be supported by the grating floor of the wedge carts. Therefore, under the direction of the FCF Customer, a hybrid configuration of the test chamber was used. Two of the wedge carts were removed from the center of the floor of the test chamber and the combustion chamber in its support stand was rolled into the test chamber and placed at the center of the hard concrete floor with wedge carts surrounding it. This hybrid configuration is shown in shown in Figure 3. The combustion chamber was inverted in its support stand to place the circulation pumps as far above the hard concrete floor as possible. Absorbing acoustic foam was placed on the upper surface of the mounting ring and also on the hard concrete floor at the foot of the support stand, as shown in Figure 3, to minimize acoustic reflections. The sound transmissibility of the combustion chamber was also investigated. A GC pump that had been previously tested at the ATL was used as the sound source because of its availability and high acoustic impedance. The GC pump was suspended inside the combustion chamber using nylon cord with the GC pump power cord was running out through an adaptor plate on the aft end of the combustion chamber.

4. FCF CIR AND FIR ENGINEERING MODEL TESTS

Engineering models (EM) of both the CIR and FIR racks have each undergone two acoustic emissions tests at ATL. The CIR EM components have been housed in an aluminum engineering rack, while the FIR EM components have been housed in a composite flight rack. The aluminum engineering rack possesses the same attachment geometry and overall shape as a composite flight rack and is used for engineering development purposes. The CIR and FIR have overall dimensions of approximately 42 inches wide, 38 inches deep, and 78 inches tall. A Ground Rack Handling Fixture (GRHF) supports aluminum engineering racks while a Rack Handling Adapter (RHA) supports composite flight racks. The CIR EM Rack in the GRHF weighed approximately 3,300 pounds with overall dimensions of 50 inches wide, 92 inches tall, and 60 inches deep. The FIR EM Rack in the RHA weighed approximately 3000 pounds with overall dimensions of 45 inches wide, 118 inches high, and 75 inches deep. The objective of these tests was to determine the baseline acoustic emission characteristics and to investigate the effects of various acoustic treatments and ATCU fan speeds.

The test support enclosure housed the FCF Customer support equipment that included a water chiller, vacuum gas cart, K-bottle of compressed Nitrogen gas, and Electrical Power Control Unit (EPCU) power supply during the first CIR EM rack test. The CIR EM Rack with its front doors open and the optics bench deployed during the most recent test is shown in Figure 4. During this latest CIR EM Rack test the sound pressure levels were measured at eight external positions that were located 2 feet from the top, front, and right side of the CIR EM Rack. The sound pressure level was also measured inside of the CIR EM Rack above the combustion chamber. The acceleration levels were measured at a total of four accelerometer positions located on the top panel of the CIR EM Rack and the ATCU housing.

The FIR EM Rack during its most recent test with its front doors open and back panel removed is shown in Figure 5. The Light Microscopy Module (LMM) was mounted to the front of the optics bench. During this test the sound pressure levels were measured at twelve external positions that were located 2 feet from the top, front, and right side of the FIR EM Rack. The sound pressure levels were also measured at two internal positions, in front of the optics bench, above and below the LMM. The acceleration levels were measured at a total of three accelerometer positions located on the top panel of the CIR EM Rack and the ATCU housing. The FIR EM Rack with the front doors closed and the external microphone locations are shown in Figure 6.

5. SPACE EXPERIMENT PAYLOADS

The ATL tested the Coarsening in Solid Liquid Mixtures-2 (CSLM-2) experiment, which is designed for a Microgravity Science Glovebox (MSG). A Glovebox is an enclosed volume that provides physical isolation of an experiment from its environment and enables crewmember manipulation of experiment hardware through gloveports. More information on gloveboxes can be found at the website http://microgravity.grc.nasa.gov/MSD/MSD_htmls/glovebox.html. The objective of this test was to determine if the acoustic emission levels emitted from the CSLM-2 experiment met the limits for Microgravity Science Glovebox (MSG) Investigations specified in MSFC-RQMT-2888A for both continuous and intermittent acoustical noise. The CSLM-2 test article consisted of the Sample Processing Unit (SPU) and the Electronic Control Unit (ECU), which were mounted to the Glovebox Base Plate. A rectilinear array of six microphones at a distance or 0.6 meters from each side of the CSLM-2 experiment was used to measure the acoustic emissions of the CSLM-2 experiment during startup, experiment powered, and experiment science activation (quench) modes. The startup and quench modes produced transient acoustic emissions while the experiment powered mode produced steady state acoustic emissions. The CSLM-2 experiment sat on an ATL support stand consisting of a modified wedge cart that had an elevated section of grating floor supported by vertical extension posts. This stand provided high acoustic transparency and access to all six sides of the CSLM-2 experiment. Small pieces of foam padding were placed between the grating floor and the Glovebox Base Plate to provide vibration isolation. The CSLM-2 experiment and the microphone array are shown in Figure 7.

6. LESSONS LEARNED

Test fixturing is an important component to successful acoustic emissions testing. An ideal test fixture securely holds the test article while providing complete access on all sides, no acoustic reflective surfaces, and does not affect or transmit the mechanical vibrations of the test article. While a bridle system provides excellent access and virtually no acoustic reflective surfaces, alignment of the test article can be very cumbersome requiring multiple adjustments of the bridle lines. Test stands provide easy alignment, but its structural members may become acoustic reflective surfaces and they may interfere with access.

The ATL is developing two test fixtures for testing of heavy test articles when the test chamber is in its anechoic configuration. The first test fixture is a pedestal stand to support test articles weighing up to 150 pounds. ATL is also developing a modified wedge cart that will have the same footprint as the existing wedge carts. It will have a grating floor at the same level as the other wedge carts to provide a continuous walking surface and a secondary elevated grating floor, whose height can be adjusted.

7. FUTURE WORK

The ATL will be involved with further testing of FCF components, subassemblies, engineering models of the CIR and FIR, and verification tests of the CIR and FIR. The ATL is currently developing test procedures and expanding its testing capability to support these upcoming CIR and FIR verification tests. In particular, a parallelepiped microphone array is being designed for both sound pressure level and sound power level testing.

The ATL currently has a 10 position 1.5 meter skewed hemispherical microphone array for performing ISO 3744 sound power level testing. The ATL is developing 19 position 1.5 meter hemispherical microphone fixture and a cylindrical microphone fixture needed for ISO 3744 sound power level testing of larger items.

Earlier this year an automated scanning sound intensity system, developed by Brigham Young University, was integrated into the ATL test chamber. This system consists of a bridge, rail, and trolley system mounted near the ceiling of the test chamber and has a telescoping vertical boom with a 2-d sound intensity probe mounted to its tip. This system will aid in identifying noise sources and acoustic leaks.

---

[1] *Acoustics-Determination of sound power levels of noise sources using sound pressure – Engineering method in an essentially free field over a reflecting plane*, International Standard ISO 3744:1994; Second edition 1994-05-1.

[2] *Pressurized Payloads Interface Requirements Document, International Space Station, National Aeronautics and Space Administration*, SSP 57000 Revision E, Section 3.12.3.3 Acoustic Requirements (April 21, 2000).

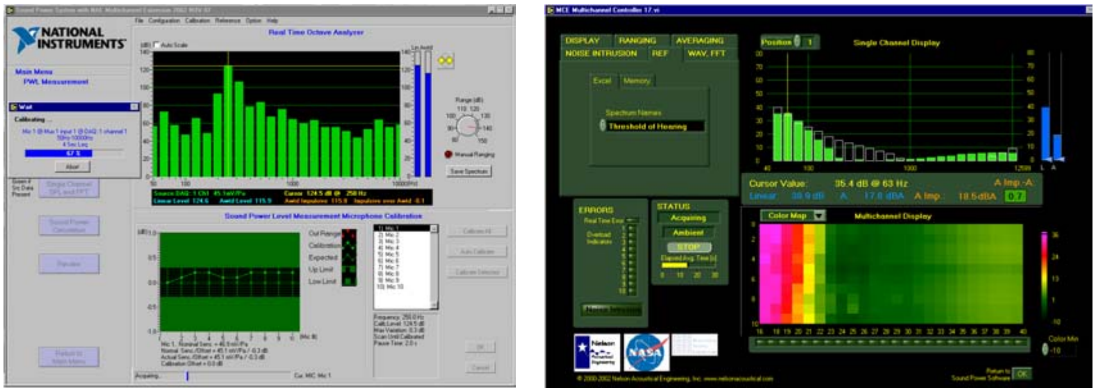

Figure 1. The ATL data acquisition system calibration window (left) and the data acquisition window (right).

Figure 2. FCF IOP hard drive suspended with bridle (left) and support equipment inside the ATL control room (right).

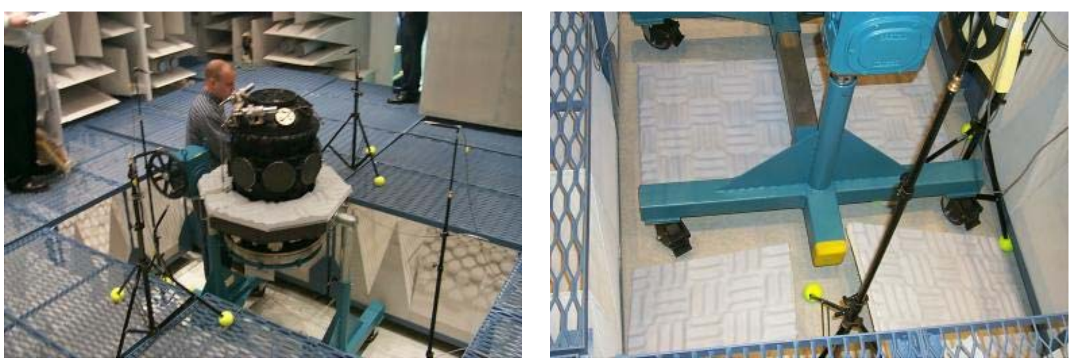

Figure 3. Combustion chamber microphone layout (left) and absorbing acoustic foam placed on hard floor to reduce acoustic reflections.

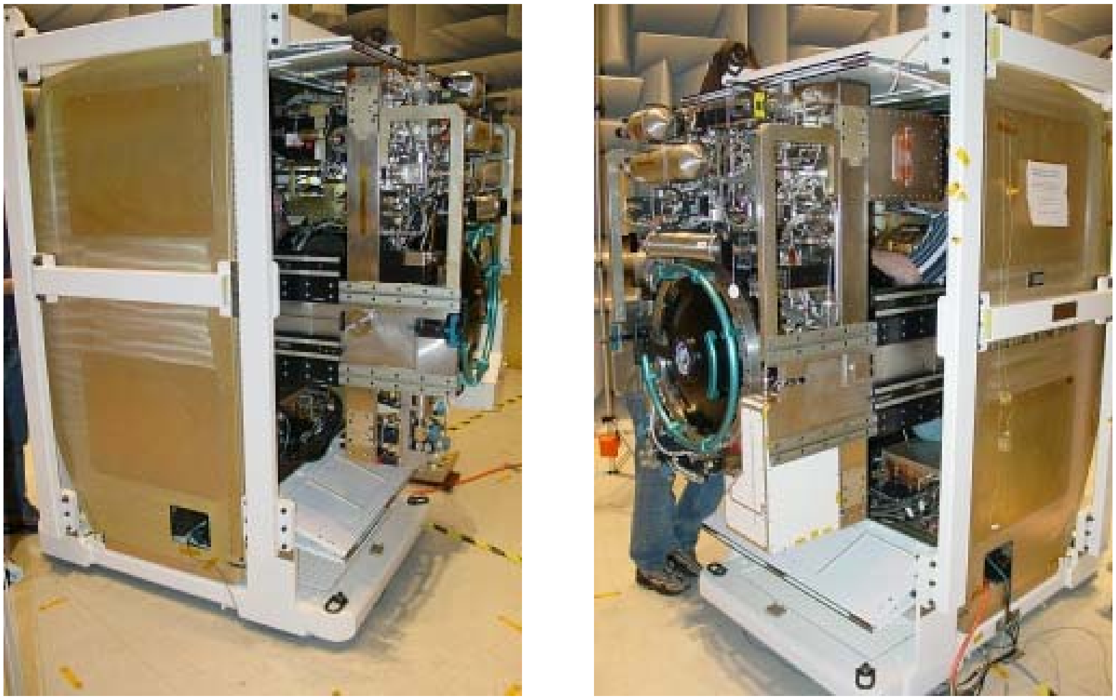

Figure 4. FCF CIR EM rack in its GRHF in the ATL test chamber with the front doors open and optics bench deployed.

Figure 5. FCF FIR EM Rack in its RHA installed in the ATL test chamber with the front doors open (left) and with back panel removed (right).

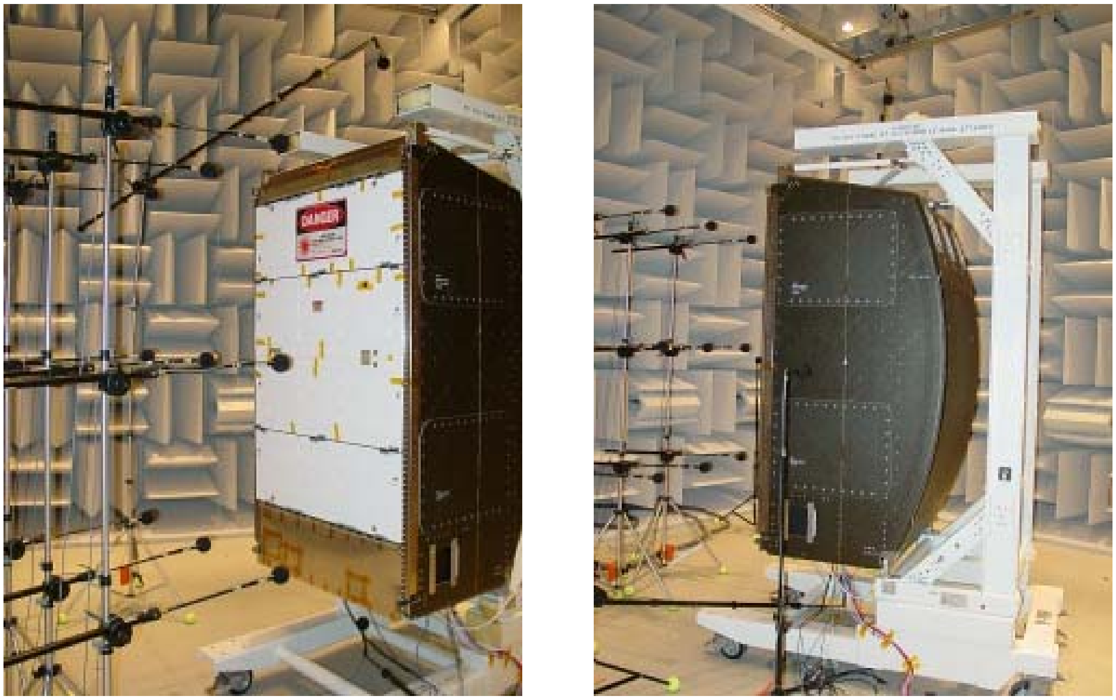

Figure 6. FIR EM Rack external microphone locations.

Figure 7. CSLM-2 experiment (left) and the microphone array (right).